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DESCRIPTION
OF A
PRACTICAL AND ECONOMICAL METHOD
OF
EXCAVATING GROUND
AND
FORMING EMBANKMENTS
FOR
RAILWAYS,
&c.;

WITH
PRACTICAL OBSERVATIONS
ON THE
CONSTRUCTION OF RAILWAYS.

By W. BRUNTON,
CIVIL ENGINEER.

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ON

EXCAVATING GROUND

AND

FORMING EMBANKMENTS

FOR

RAILWAYS,

&c. &c.

For several years the subject of railways has constantly been before the public, and there are very few who need to be informed that the cutting and removing of ground in order to obtain straight and level lines, constitute a very large proportion of the expense incurred in the formation of them; whilst the experience of every day is adding more value and importance to these properties, demonstrating the propriety of avoiding, as much as possible, curves and declivities. Any method, therefore, which will lessen the cost of excavating and removing ground becomes more and more desirable.

With the exception of the dredging engine, mechanism has left this subject almost untouched, but it is worthy of remark, that by that useful machine ground is excavated even from under twenty feet of water, and delivered into barges, at less cost than it has usually been done for on dry land.

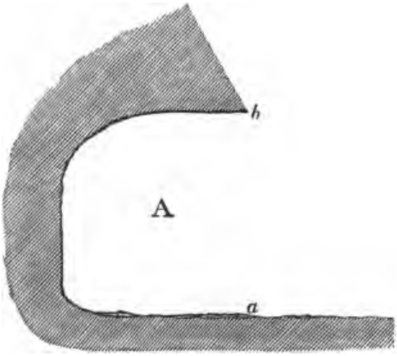
Having been practically engaged in bringing the dredging machine into effective and beneficial operation in the deepening and improving of several harbours, and having had more than an ordinary share of experience in the application of machinery to new purposes, I approach this subject with the confidence of effecting an important public benefit, having invented a system of machinery suited to the purpose, viz., an apparatus to facilitate and improve the excavation of ground and the formation of embankments, for which I have obtained His Majesty's letters patent.

In offering further observations on this subject, I beg leave to notice particularly, that in excavating ground I bring its specific gravity in aid of that operation, and the consequence of this will appear from the following considerations:

Suppose the tenacity of the ground to be - 10
The specific gravity of the same to be - 5
—
If both are to be overcome they will be equal to a resistance of - - - 15

But if we can bring the specific gravity of the ground (or its natural weight) to oppose its tenacity, then we have only to overcome a resistance of 5, or $\frac{1}{2}$ of the former as

tenacity	10
sp. gravity	5
	5



To illustrate this more familiarly:—the tenacity and weight are both to be overcome in digging up the bottom of the excavation A at *a*, whilst in digging down the roof at *b*, the weight assists in overcoming the tenacity.

This operation may receive yet further illustration by considering the great quantity of ground which a common plough, worked with horses, will disengage in a few hours, and then imagine the effect of a plough if it were worked *across* the face of a piece of ground so steep, that the earth or mould as it is detached would, by its own gravity, fall away from the ploughshare to the bottom; and still further suppose the effect of the plough if it were turned upside down, and cutting the roof of the excavation, where the ground would not only fall or roll away when cut, but would act with all its weight to detach itself; and where, if the adhesion of the ground were only equal to its specific gravity, it would fall away at a touch.*

In the study of this subject I soon found that if mechanism be admitted at all, it will take a wide range, and will claim an application more or less extensive and advantageous in every department of the process of forming railways. For the quantity of earth which an excavating machine, or men working upon this principle upon stages constantly elevated to the work, would displace, rendered it needful to adopt a more expeditious mode of removing it. This accomplished, a better means of depositing the stuff becomes necessary, and the whole made it desirable to adopt some efficacious mode of consolidating the embankment as the work proceeds.

---

* I would beg leave to recommend, as a sort of demonstration of this principle, that a workman be made to excavate a space in the face of a sloping bank, and there let him extend the space upwards by cutting the roof of it, as at *b*, this may be done in a few minutes, and though the workman must necessarily be placed in disadvantageous circumstances with regard to his work, yet a trial of this kind will point out what may be done by a well arranged means of excavating earth upon this principle, and the importance of carrying it into practical operation.

The first part of the apparatus referred to, is a machine consisting of a series of cutters fixed to a beam, which, on its being longitudinally moved, urges the cutters into the ground and displaces it, after the same manner as a plough, in which movement the cutter-beam is guided by what I call the guide-frame, which lies upon the face of the cutting, and is moveable in the direction across the line in which the cutters act, in order to bring them into fresh hold with the ground every succeeding stroke. A, A, fig. 1, plate 1.

This guide-frame, A, A, is supported at one end upon a moveable standard B, and is capable of being moved in the direction of its length to suit the nature and shape of the excavation.

On this moveable standard, also, is fixed a vertical spindle and chain barrels, from which, chains, passing over suitable guide-pulleys, and fixed to the cutter-beam, give a reciprocating motion to it.

The other end of the guide-frame is supported upon the face of the cutting, suspended by a chain from a moveable crane, D, fixed upon the surface of the ground at the head of the cutting, by this crane the guide-frame is raised at every stroke a certain height, whilst the cutters are at the extremity of their back range, in order that they may take sufficient ground for the succeeding cut. That this may be done with ease, the cutters are attached to the cutter-beam at distances one foot, or thereabouts, less than I make the cutter beam to move, and the cutter-beam moves in a line so much oblique to the line in which the cutters are fixed to the beam, that the excavation made by the last set of cutters on the beam shall make room for the next set of cutters in advance to be raised up, when at the extremity of the back range as described, and enter another cut, and so the excavation of this set of cutters makes room for the set next before it, and so on through the whole, as shewn fig. 4.

A set of cutters consists of three cutters or ploughs applied and attached all to one gudgeon, so that they project different distances, and of course cut different depths into the ground, for the purpose of one relieving the other in cutting, and offer less resistance.

If the stratum, or thickness to be cut, be eighteen inches, then the first cutter projects into the ground six inches, the next twelve inches, and the next eighteen inches, all being fixed to a gudgeon, which rests in a cast-iron saddle screwed to the under side of the beam, (see figs. 2 and 3), so that in the event of a stone falling, the cutters while they are held up to their work are not irresistably so, but will yield and give way with undue pressure also, by turning the gudgeon; the cutters are thereby thrown out of the way whilst the guide-frame and cutter-beam descend the face of the cut to begin a new stratum of excavation.

There are two such apparatus as I have described, one on each side of the cut, and the chain-barrels, by means of which the cutter-beams are moved, are operated upon by the same power, and in such a manner, that whilst one cutter-beam is going up the other is coming down. The lower six or seven feet of the cutting is excavated by hand labour, and about seven feet high from the bottom of the cutting a moveable stage or platform is applied, which defends the men working in the lower part, and also receives the stuff cut from the upper part of the excavation, from whence it is discharged into waggons which can be run under the stage. The operation of excavating is conducted in the following manner: I project the cutters so far from the cutter-beams that they enter the ground on the face of the cutting eighteen inches, or any other depth it may be found best to cut at one thickness or stratum, which I begin at the bottom of the face, having previously excavated a groove or space into which the cutters are projected, and by their reciprocating motion cut from the top or roof of this space or groove, which is thus constantly enlarged upwards until the cutters reach the upper surface of the ground, and the whole stratum has been removed from the face of the cutting.

Then the standards, bearing the moveable frames and other parts of the apparatus, together with the crane by which the guide-frame is elevated and lowered, are to be drawn onward by means of cranes provided for the purpose, to take another stratum, and the guide-frame and cutter-beam are lowered down until the cutters can enter the groove or space as before. Whilst the excavation is proceeding as described, the space or groove to begin another stratum is prepared by means of a bar F F, which moves up and down upon the slope by the same power and means that moves the cutter-beams, in this bar or rod strong pins are fixed, about one foot each asunder, along its whole length, any one of which acting against an excavating tool inserted into the face by a workman will, by the motion of the bar, urge such tool onward through the ground whilst the outer end of the tool is held by the workman who walks up the excavation during the operation. Also by the returning or downward motion of this rod, the stuff which falls upon the slope from the upper cutting, and will not slide down of its own accord, is moved onward by rakes which the workmen attach to any of the pins during the descent of the rod, and disengage the same during its ascent. Both the moveable standards and the moveable cranes described are supported and move progressively along beams of timber laid for that purpose as the work goes on.

The stage for receiving the stuff is constructed with holes through which it is discharged into the waggons below; and it rests and moves upon frames, one half of which can be moved onward, whilst the other half sustains the weight, the whole operation being done by workmen below.

The annexed sketch fig. 1, plate 1, is intended to represent this machine in operation upon a cutting thirty-five feet deep, the slopes one and a half to one, and the face of the cutting half to one. Having four or five sets of cutters in each beam which moves at the rate of only twenty-seven feet in one minute, and each cutter on an average cuts a section six inches wide, four inches thick, and twenty-seven feet long, each minute, which would be four and a half cubic feet for each cutter, and twelve cutters or four sets will give fifty-four cubic feet of ground per minute, or two cubic yards; or say 200 cubic yards every two hours, leaving twenty minutes in that time for shifting the apparatus, or 1000 yards in ten hours, leaving in that time one hour and forty minutes for the shifting, for which all necessary arrangements are made by the mechanical attendants during the process of excavating, so that no time is lost.

The expense of excavating by this machine will be as under:

	£.	*s.*	*d.*
Cost of machinery, steam-engine and chains, moveable stage, &c., 1800*l.*, daily interest for ditto	.	15	.
Mechanic and assistant at top machinery - - - per day	.	7	.
Two men attending the cutters - -	.	6	.
One man attending to elevate the frame - - - - - -	.	3	.
One ,, for engine - - -	.	3	6
One ,, general assistant - -	.	3	.
Ten men loading waggons from stage	1	10	.
Eight ,, cutting under the stage -	1	4	.
Four ,, at slopes - - -	.	12	.
One man, mechanic, under stage -	.	4	.
One ,, blacksmith, and assistant	.	8	.
Coal, oil, tallow, &c., for engine, &c.	.	10	.
Contingencies - - - -	.	12	6
For cutting and loading 1000 yards of stuff - - - - -	£6	18	.

is equal to $1\frac{65}{100}$ per yard.

But it is manifest that, if needful, the speed of the cutters could be increased, without risk, to double that I have stated, say to fifty feet per minute, which would in the same proportion increase the quantity excavated, say upwards of 1800 cubic yards in ten hours.

Another mode of excavating is represented in figs. 4, 5, 6, and 7, in plate 2, by manual labour; the men being placed on stages which are elevated as the ground is cut upwards, so that they are always advantageously situated with regard to the work, whatever sort of tool they may use. Fig. 6, shews a man working with a grafting tool, which by means of the straps and roller (fig. 14), supported under the rail, c, he is enabled to urge, in a horizontal direction, with the same or more force than he could do by applying his foot to it, in the usual manner, and the piece of ground detached, aiding the operation by its whole weight, immediately falls away from the tool, and, conveyed by a shoot into the waggon, is virtually loaded at the same moment. It will be obvious, that by this expedient, the most laborious part of the work, as usually conducted, viz., the detaching the piece after the tool is inserted, and raising so as to load it into the waggon or barrow, is completely saved; and the man is supported by the rail, against which he may lean, and, if needful, he can, by pulling himself down, add to his muscular strength his natural weight in urging in the tool. Men thus employed may work about one yard and a half asunder.

In strong tenacious gravel, a tool, as represented in fig. 8, is used with great effect. The stage in that case is fixed to two cheeks of cast-iron, which slide up the face of the cutting, like a sledge, and is suspended to two chains by which it is raised as the work proceeds. The tool is suspended to another chain which traverses the whole length of the connecting-bar, whilst its heavy outer end is raised by the workman and returning with all his force added to it, urges the two points of the tool up into the projecting piece of ground; then, by a side motion, one of the points becomes the fulcrum of the lever which detaches by the other point a piece of ground. Two men may very advantageously be employed with one of these tools (fig. 7), and the stages may either be raised by the men at work upon them, or where great expedition is required, a man may attend two or more stages for that purpose. Two men working this tool may be placed upon the stages at about one yard and a half asunder.

This mode of excavating I have applied to cutting strong clay or gravel, and I am confident that fifty men may very advantageously be employed in excavating a cut thirty-six feet deep, thirty-three feet at the bottom, and the slopes one and a half to one perpendicular, and that in moderately firm ground they will cut and load 1200 cubic yards per day, which would not cost more than 2*d.* per cubic yard, including the cost of the implements, &c. &c.

Much advantage is to be obtained by bringing the process of excavating to some system and order, by which not only the time for the execution of such works might be calculated with greater accuracy, but it would enable the engineer to carry on his operations with more precision and certainty, to bring forward the water-drains close to the cutting, and also to carry the railway, for the conveyance of the stuff, close to the face, avoiding, in a great measure, the use of barrows, &c.

The next part of the process in order is the conveyance of the waggons between the cut and the embankment, which is effected by two railways parallel to each other, with an endless rope passing along them, and by attaching the waggons to the rope by a pair of jaws acted upon by a weight, they are conveyed in either direction. In this manner ground will be moved without the aid of horses, and at much less expense, not merely in the substitution of steam for horse power, but in avoiding the great expense consequent on making and maintaining a road for the horses to work upon over a new line, and the constant derangement of the rails from the propulsion of the horses' feet.

The cost of this mode of conveyance will be found nearly as under; say, for conveying upon a level line 1200 cubic yards of ground one mile in ten hours; each waggon capable of carrying three cubic yards; a five and a half inch rope, moving at the velocity of 200 feet per minute, will convey upon a mile of railway twenty-five loaded waggons in one direction, and twenty-five empty ditto in the other; this will require a 12-horse engine, which, with suitable pulleys and apparatus to give motion to the rope and waggons, with rails and rollers, 3000*l.*,

For which outlay say, -	1	5	.	per day
120 waggons - - -	1	5	.	,,
Oil, tallow, and coal -	1	.	.	,,
Ten attendants - -	1	15	.	,,
Rope - - - -	1	10	.	,,
	£6	15	.	upon

1200 yards, about = 1.15 pence per yard per mile.

Much inconvenience and expense have been occasioned by the shrinking or settling of embankments, sometimes owing to the nature of the stuff of which they are composed, or the want of proper drainage, and, not unfrequently, the manner in which the materials, good of their kind, are laid in the formation of the embankment.

There is a subsidance or consolidation takes place in earth-works generally, by exposure to the weather and seasons, which, perhaps, can never be altogether avoided, but that derangement consequent on the mode of construction may, in my opinion, be prevented, or at least greatly diminished.

When the earth is discharged over the face of a bank the aggregation is oblique, and, therefore, the particles in their descent are rather suspended than laid solidly in place, for each rests upon an acclivity only flat enough to resist its progress downwards, particularly towards the bottom of the slope, where the materials losing their velocity are found arranging themselves in the most open and loose manner possible, altogether unfit to become the basement of the superincumbent mass, without crushing and subsiding, during which change the upper and more solid part of the embankment is subjected to constant disruption and slipping, which tend rather to separate than consolidate the particles, and till these effects cease, they prevent the commencement of that ultimate consolidation which must take place before the embankment becomes permanently fixed.

Having briefly pointed out the defects in the construction of embankments, I will now describe the means by which I propose to improve such work, aiming at the same time at as little departure as possible from the usual mode of proceeding. I propose that the middle section of the embankment, as shewn (fig. 8, plate 1), be formed by discharging the stuff over the end as usual, then at any convenient distance from the end, let the stuff be discharged over each side by an inclined plane (fig. 7), constructed with rollers supporting an endless floor of strong sacking supported on cross pieces of wood attached to two endless chains working over rollers, by which the stuff will run down at such an acclivity as to throw it a sufficient distance to form the foot, B; and let the deposition be so conducted, that in its descent over the inclined plane, it may impinge against the growing surface, at *a*, and roll down toward the body of the embankment already formed. The slipping tendency of these portions of the embankment will be opposed to each other, and will settle or subside perpendicularly, and, consequently, consolidate by the first and every succeeding movement. The embankment thus formed may be further improved by the application of the rollers described in the specifications, to crush and consolidate the stuff at the bottom of the slope, as the middle section proceeds, which would avoid much of the inconvenience always attendant upon the subsiding of an embankment, even when it takes place in the best manner.

I have thus explained the nature and application of the apparatus for excavating ground and forming embankments, by which it will appear that ground may be cut, moved a mile, and laid in the embankments, for less than one half the usual cost; and what I have stated I feel confident will be realized, at the same time I am sufficiently aware that much resource and perseverance are necessary to overcome the obstacles and prejudices which will present themselves in bringing it into extensive application, and to obtain the full benefit of the principle laid down. But a subject proposing a saving of so much expense as well as time in the execution of works now about to be undertaken, presents a prospect of great usefulness, and adequate remuneration, well calculated to nerve the resolution, and support one through the ordinary discouragements likely to attend the first application of machinery to such like purposes. The value of what I propose may be apprehended from the estimated cost for the removal of ground upon the London and Birmingham railway being about one shilling per cubic yard; and that the saving of only one penny per yard upon the quantity would alone amount to about 50,000*l*.

Since I invented this machinery and obtained a patent, I have engaged extensively in other avocations which render it impracticable for me to give it my personal attention, but desirous that a subject which has cost me much labour, study, and expense, should be made extensively beneficial, and brought to practical application; I, therefore, as patentee, will act with great liberality with those who feel disposed to carry any part of what I have described into effect.

PRACTICAL OBSERVATIONS

UPON THE

CONSTRUCTION OF RAILWAYS.

I NOW offer a few observations upon the construction of railways.

The greatest work of this kind yet executed is the Liverpool and Manchester railway, which affords a new and important field of experience, wherein very much is to be learned, confirming the truth of many things before held to be doubtful and suggesting many improvements of which that great work is yet susceptible.

An inspection of this railway will demonstrate the desirableness of having the rails so strong as to admit of no sensible deflection between the supports, and also that the rails be permanently fixed to the chairs, and that there be a good practicable method of consolidating the blocks adjusted to suit and support the chairs, that the rail may be supported firmly, quiescently, and unconstrained, and that the materials, viz., the rails, chairs, and blocks, be fixed together in the greatest quantities that can be consistent with the expansion and contraction (to which the rails particularly are subject), in order to present by their united vis-inertiæ the greatest resistance to tremour and displacement from the rapid transit of the waggons.

There seems, however, great difficulty in attaining these desiderata, whilst the present construction is followed.

For the rail and the chair may be made sufficiently strong and immoveably united together, yet the impracticability of setting the blocks to fit and permanently to support the chairs still remain.

The frail and imperfect nature of the fixture by which the chair is attempted to be attached to the block is unworthy of the name.

Besides, the blocks being fixed or rammed in the ground, having their base about fifteen inches below the centre of the rail, cannot be moved to greater or lesser distance by the expansion or contraction of the rail, but by such a movement are necessarily detached in a very short time, however much pains may have been taken in laying them.

Add to these the very defective and unsatisfactory mode of readjusting the blocks where they have been sunk or displaced, and much of the cost under the item of "*Maintenance of the*

Way," is to be attributed to the defects before noticed, for it is well known that the great expense incurred in the maintenance of the way, is for refixing the rails, chairs, and blocks, which are neither broken nor worn out, but simply displaced by the action of the carriages. To obviate some of those defects by concentration of the strength and weight of the materials, and also to obtain a greater degree of solidity to the whole system, I propose to use a cast-iron chair with projecting wings, sufficiently large to rest upon the ballast, and a keel piece, as represented in fig. 9, plate 2. Its weight need not be more than ninety or one hundred pounds, it is so strong that the rail may be immoveably fixed in it, and the angle which the wings make to the horizon presents the easiest and most efficient method of consolidating (or if need be raising) the chair by driving in hard materials under them with a blunt ended pick, which operation may be performed at any time, offering no interruption to the traffic. The stability of the chair during the transit of the waggons would be at all times the best proof of its being in good order, and the motion of any chair (which would be very easily observable), would point out distinctly where it was defective; their construction as already stated presenting the most perfect means of improvement by bringing all the chairs to an equal and permanent bearing.

Another advantage in the use of such chair, instead of the common stone-block or sleeper, would arise from the bearing-surface being so near to the axis of the rail, that its elongation or shortening will push or draw the chair along with it without getting loose, or in any sensible degree being injurious, even in an united length of sixty feet, and if the two rails were united in their whole length by the cross bars, (fig. 10, plate 2,) they will present an aggregate weight of consolidated iron materials, of about three tons, supported firmly and uniformly at every base, without constraining the rail or being constrained by its rigidity.

On comparing the cast-iron chair (fig. 9) with the common stone-block, and cast chair as represented (fig. 11), by the obvious rule, that the stability is, as the width of the base is to the perpendicular height. It will be seen that the proposed chair is nearly six times more steadfast than the common stone-block, which, however large, weighty, and expensive they may be made, must necessarily be far inferior in stability.

It will be apparent that the keel-piece, pressing laterally against the ballast on which the whole weight of the railway and carriages rest, must more effectually resist any lateral strain than the common block, borne up sideways, only by stuff, at best, rammed down around it, but in consequence of the frequent occasion to raise and reset them, the materials by which they are supported laterally are loose and unconsolidated.

Another object of importance will be attained by the adoption of such chairs, viz., the reduction of about one half the thickness of the ballast, and also a saving of about twelve inches in the depth of the water-drains along the side of the railway.

The substitution of iron chairs instead of stone blocks will at first sight appear chimerical to many, on account of the apprehended expense, but this objection will vanish when the subject is fairly investigated. The stone-blocks on several lines of railway are estimated at 4*s*. or 5*s*. each, which, with the ordinary chair and fastenings, will amount to 5*s*. 6*d*. or 6*s*. 6*d*. each. A chair-block, as represented in fig. 9, weighing ninety pounds, may at the present price of iron be obtained for 7*s*. each, or should it be thought well to enlarge the base considerably, it may then cost 8*s*. or 9*s*. But even this advance would be more than met by the saving of the ballast and the less depth of the drainage, besides the very great convenience and facility experienced in laying and adjusting. Such chairs will also effect a very important saving in time and accuracy in the labour of fixing, rendering the railway at once much more perfect, besides the practicability already alluded to of being retained in the most perfect state of repair, without the inconvenience of taking up a single chair, or obstructing the use of the railway a single hour; and should any circumstance render it needful to replace these chairs they will generally fetch forty per cent. of their first cost, whilst the stone blocks are, by frequent replugging, split and rendered useless.

OBSERVATIONS ON RAILWAYS,

PRINTED FOR PRIVATE DISTRIBUTION IN MARCH, 1834.

From an early and continued acquaintance with the capabilities of railways, and of steam as a propelling power, I have long looked for the arrival of the present juncture, when the public mind should be impressed with the importance of such means of communication.

During the period of my experience on this subject many very ingenious minds have been employed, and great improvements have been made; and I feel assured that the science, talent, and industry which are now engaged upon it, will ultimately overcome the obstacles which yet present themselves, and render railway conveyance much more complete and beneficial than it has yet in any case become.

As one taking a deep interest in this subject, and having borne a humble part in bringing it to its present position, I feel it a duty to draw public attention to the following brief observations, and more especially at the present time, because the proposition I have to make, is of a nature so fundamental, that, unless it be attended to now in the outset of extended lines of railway, however much it may be desired at a future period, it will be next to impossible to carry it into effect, or rectify the mischief which, in my opinion, it is calculated to remove.

Those who are interested in railway affairs are fully aware of the great expense connected with the repairs of locomotive engines, where the transit is quick, as upon the Liverpool and Manchester Railway; and that, notwithstanding the ingenious efforts that have been made, and the promise some of them have given, the expenditure is yet so alarming as not a little to shake the confidence of the public in the whole project.

I have narrowly watched the expedients resorted to, and also their effects; and having extensive experience in the application of heat to generate steam, I feel confident that the cause of the expense in the repairs of locomotive engines is the intensity of the heat now applied to the boilers, the consequent deterioration of the tenacity of the parts exposed to its action, and the expansion and contraction of parts so contiguous as to occasion fracture; nor do I imagine that any practical engineer will call this in question. But how is it to be obviated? I answer, by increasing the area of the fire, reducing its intensity, and more uniformly applying the heat to the boiler. But this is next to impossible where the rails are only four feet eight inches asunder, as upon the Liverpool and Manchester railway; and until we have a wider base, on which to carry locomotive boilers, their destruction, and the cost of repairs, in my opinion, will continue to be an alarming item of expense.

I am fully aware of the increased cost attendant on such a measure, and also of the practical objections which may be urged against a wide railway; nor do I overlook the inconvenience connected with departing from the established width of the Liverpool and Manchester, and the branches united with it; but all these, in my opinion, are of minor consideration with the reduction to proper and reasonable limits of the expense of locomotive engines.

It is certain that the present distance of the rails was fixed upon at a time when we were destitute of the experience now supplied by the Liverpool and Manchester; and believing that very great benefit would accrue from an increased width of railway as a preliminary measure, I would respectfully suggest the propriety of investigating this subject; whilst, if there be any advantage in what I propose, it may be adopted upon the railways now in progress, or projected.

W. BRUNTON,
Civil Engineer.

3, Charlotte Row, Mansion House,
March 8th, 1834.
Now
Cwm Avon Tin-Plate, Copper, and Coal Works,
Glamorgan, South Wales.

The above remarks were made after having carefully examined the working of the Liverpool and Manchester railway, and I am not aware that any important saving has been effected in the durability of locomotive boilers which would render the observations inappropriate now.

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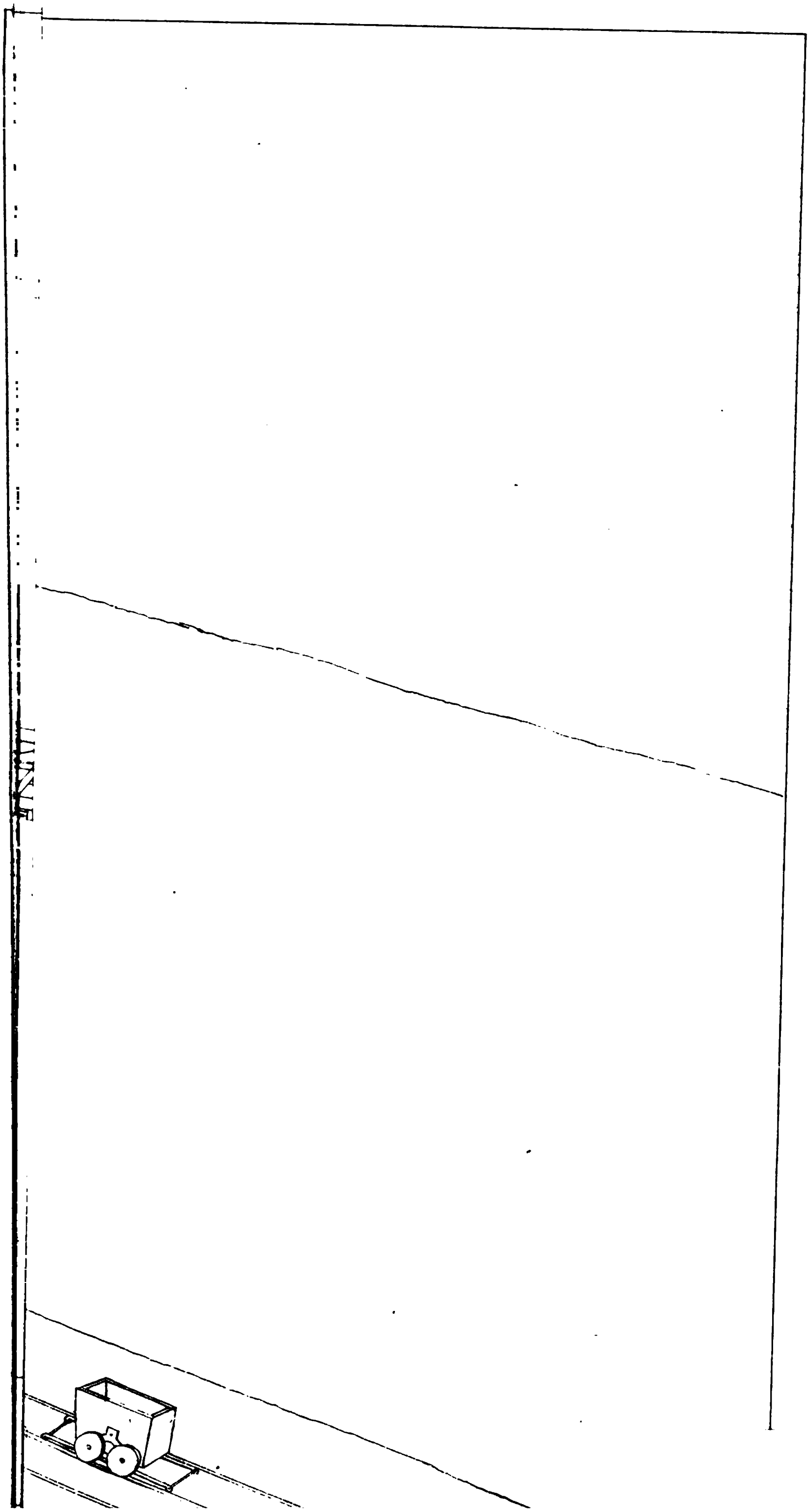

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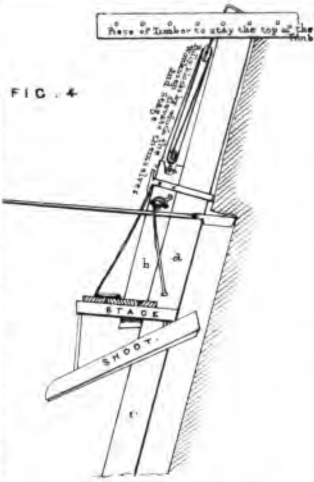

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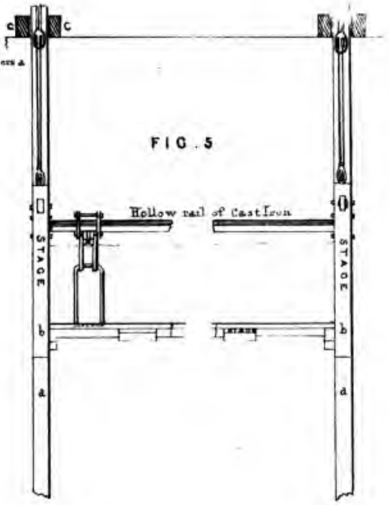
FIG. 5



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